mRICH for EIC YR

Xiaochun He, Murad Sarsour, Marco Contalbrigo and Zhiwen Zhao

on behalf of the EIC PID Consortium (eRD14)

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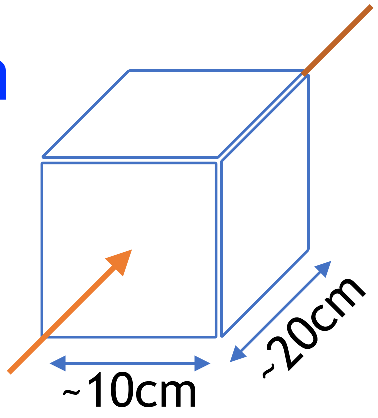
YR progress report on May 1, 2020

Scope of the present mRICH parameterization for YR

To a first order estimation of the external requirement (i.e. tracking) for achieving the mRICH performance, our discussion will be mainly focused on a special case which will allow us to calculate the mRICH properties analytically.



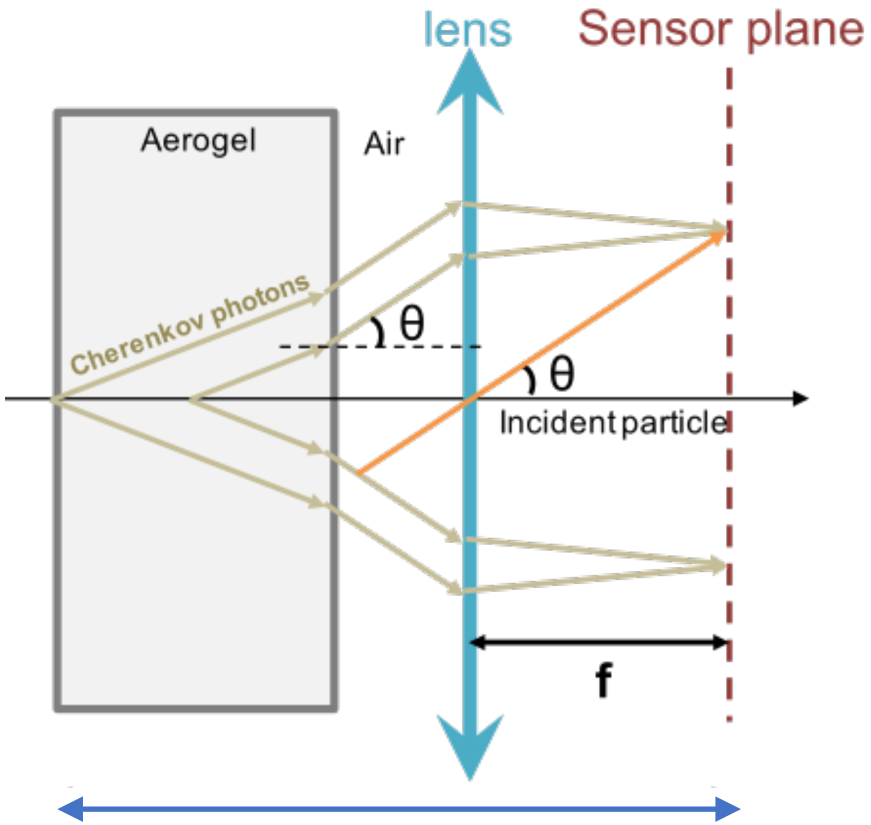
This special case is that the particle is incident normal to the front of mRICH at the center. The mRICH performance with varying momentum direction and magnitude are part of the ongoing work which includes GEANT4 simulation and prototyping studies.

mRICH
Internal Characteristics

Design tooling: analytical calculation, GEANT4 simulation and prototyping

See Murad Sarsour’s presentation on fast parameterization

EIC mRICH – Working Principle



~ (aerogel thickness + lens focal length)

(Not to scale, for illustration purpose only)

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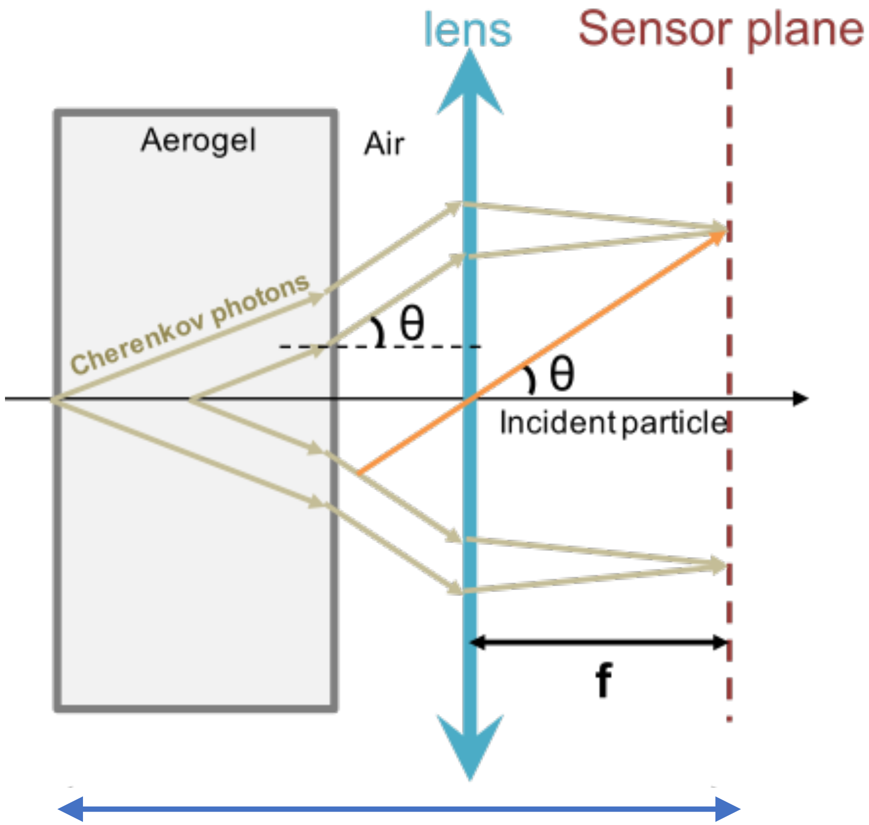

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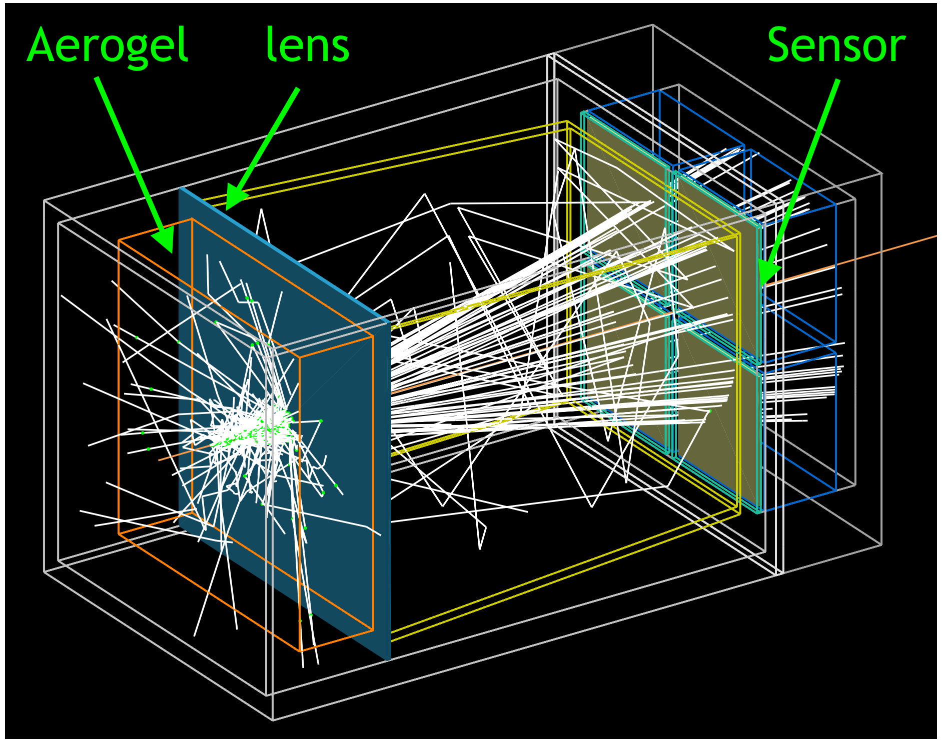
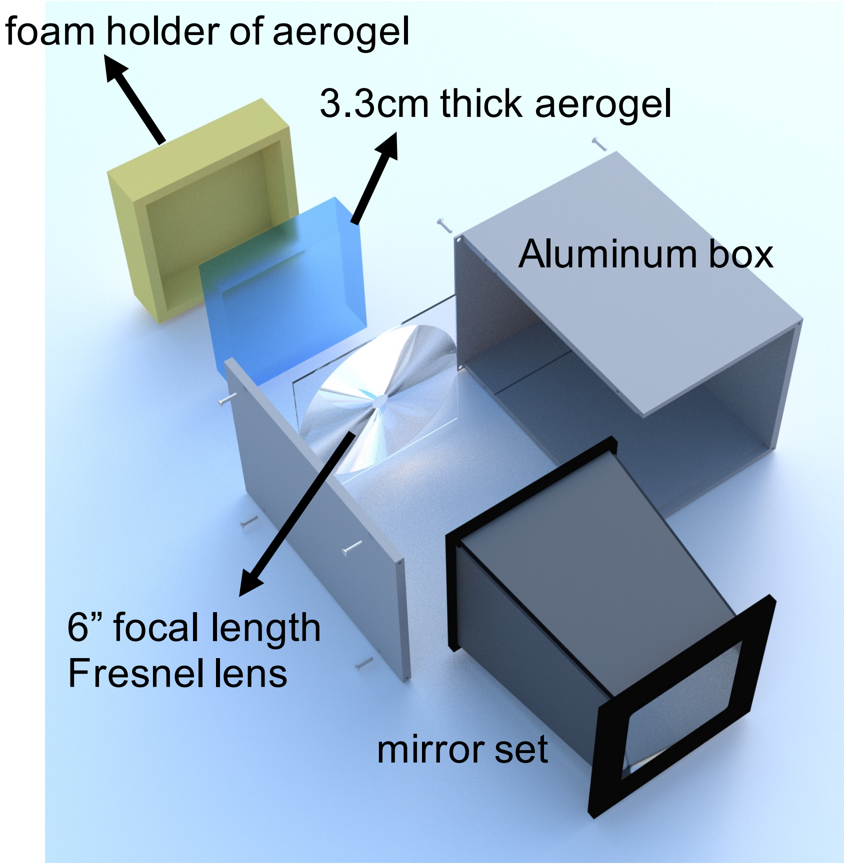
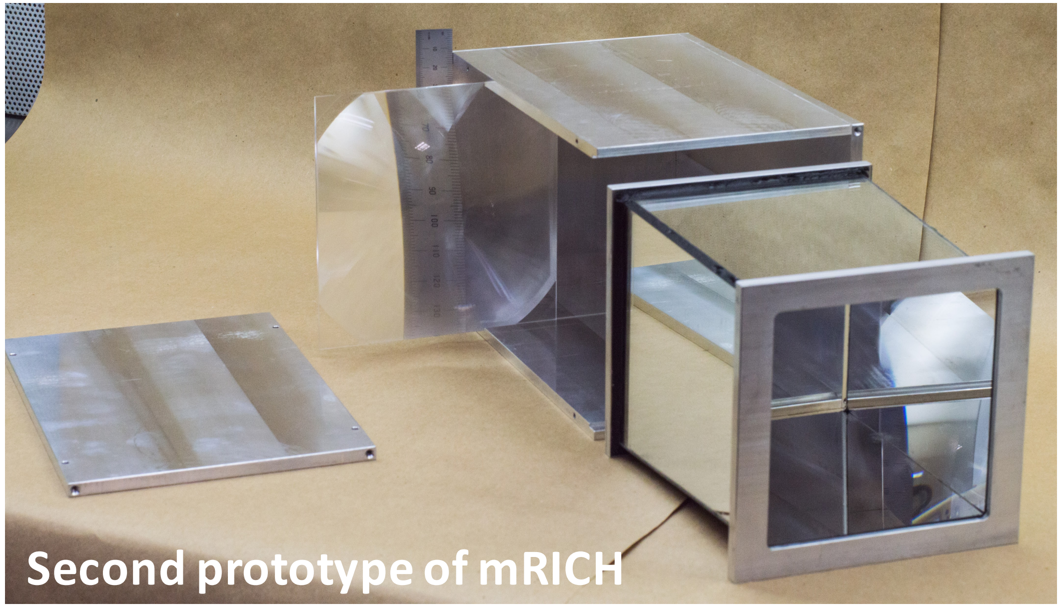


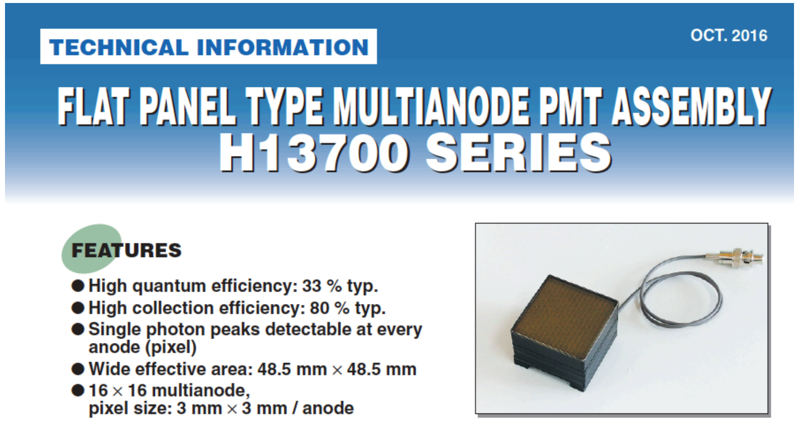
Geant4 Simulation

With realistic material optical properties

2nd mRICH Prototype (readout electronics not included)







TECHNICAL INFORMATION

OCT. 2016

FLAT PANEL TYPE MULTIANODE PMT ASSEMBLY
H13700 SERIES

FEATURES
- High quantum efficiency: 33 % typ.
- High collection efficiency: 80 % typ.
- Single photon peaks detectable at every anode (pixel)
- Wide effective area: 48.5 mm × 48.5 mm
- 16 × 16 multianode, pixel size: 3 mm × 3 mm / anode

1. Longer focal length (Fresnel lens)
2. Smaller pixel size sensors

mRICH Key Components - Optical (per module)

Components	Functions	Specs/Requirements	Risk	Mitigation
Mechanical (shoe box)	Supporting frame structure and light blocking.	Dimension: 11cm x 11cm x 20cm. Need mounting fixture designed for installing an array of mRICH modules.	None	Light and steady
Fresnel lens	Imaging focusing, UV filtering	Focal length ~6" (acrylic for UV filtering)	None	Good optical characterization scheme will be needed.
Mirrors	Reduce Cherenkov photon loss when particle is incident at a larger angle.	Rough dimension: Trapezoid shape: 15cm (height) x 11.5cm (width1) x 10cm (width2)	None	Good optical characterization scheme will be needed.
Aerogel radiator	K/pi separation between 3 to 10 GeV/c, e/pi separation ~2 GeV/c	10 cm x 10 cm x 3cm, n = 1.03	Limited number of producers (one in Japan and one in Russian)	Extensive knowledge in the INFN group (led by Marco Contalbrigo) at CLAS12.

mRICH Key Components - Sensors & Readout (per module)

Components	Functions	Specs/ Requirements	Risk	Mitigation
Photosensor (MCP-PMT)	Single photon detection and good spatial resolution; good timing resolution about 50 - 100 ps; low dark count rate	Magnetic field tolerant and radiation hardness (the same as for dRICH). 3mm x 3mm (or less) pixel size	Cost, R&D timeline, a single manufacturer for high quality volume production	R&D test needs to be performed in close collaboration Junqi Xie at Argonne, Mickey Chiu and Alexander Kiselev at BNL
Photosensor (SiPM - matrix)	Single photon detection and good spatial resolution (~ns)	Magnetic field tolerant and radiation hardness (the same as for dRICH). 3mm x 3mm (or less) pixel size	Radiation damage (mainly from neutrons)	Proper cooling (tested in the 2nd mRICH beam test in 2018); further R&D is needed.
Readout electronics	Amplify and shape single photon analog signal.	Low noise, time resolution is ~0.5 ns; high density connectors; modular.	Chip development	Closely working with JLab, INFN and Hawaii groups for readout development.

mRICH

Pros	Cons
Sweet momentum coverage for K/pi separation from 3 GeV to close to 10 GeV. It also provides the capability of e/pi separation around 2 GeV.	Photon sensors and readout electronics see direct hits of particles. Radiation hardness concerns.
Modular design for array installation. Each module is independent with other modules and can be calibrated separately. Projective capability.	Acquire aerogel tiles and maintain their long-term stability (optical)
Performed two beam tests. The working principles have been validated in the first beam test in 2016 and the results have been published in NIM A. Further beam tests with tracking capabilities are expected and under planning.	Need high density photon sensors working in magnetic field.
Full GEANT4 simulation has been developed and verified using the beam test data.	Could create extra dead areas between modules. [Could be minimized by projective and creative integration schemes]
An array of mRICH modules have been implemented in the sPHENIX for EIC simulations.	

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a lot

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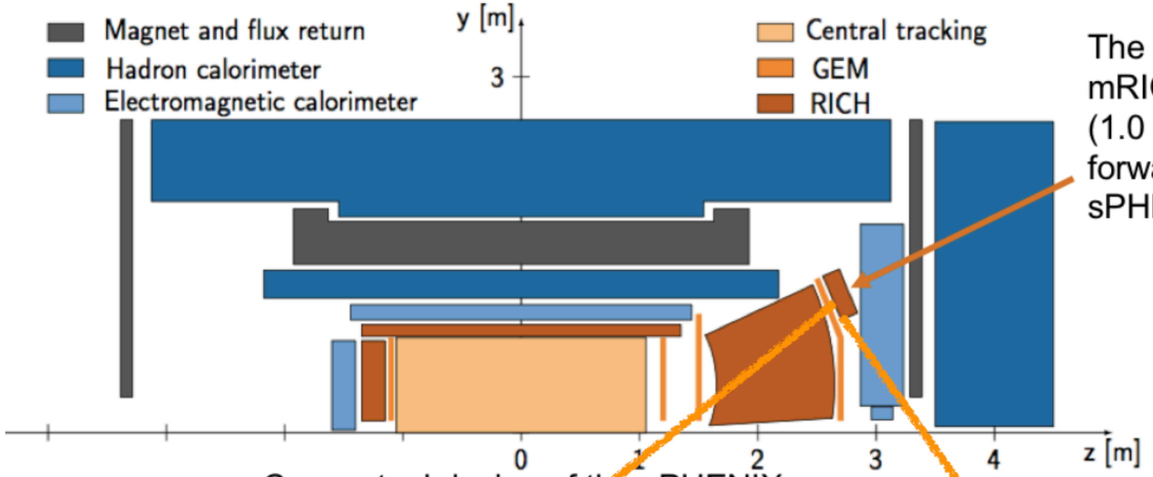
a lot

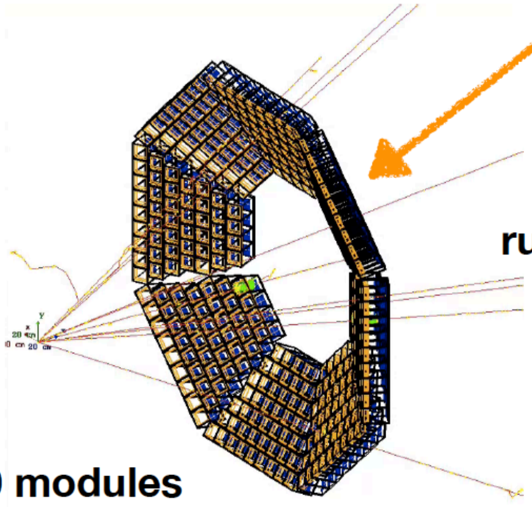
a few

From a single module to large arrays



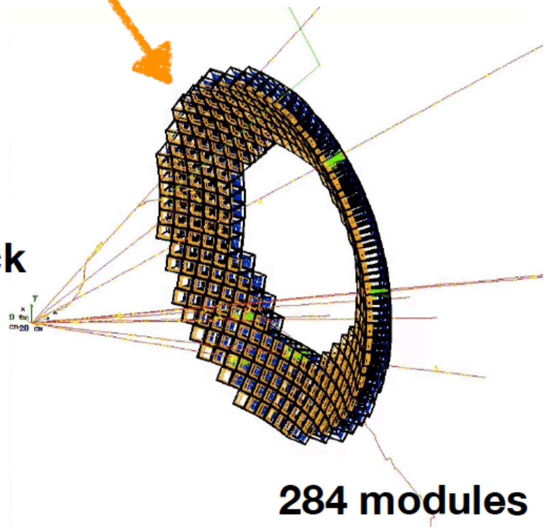
Conceptual design of the sPHENIX

The proposed mRICH coverage (1.0 < y < 2.0) in the forward region of sPHENIX.

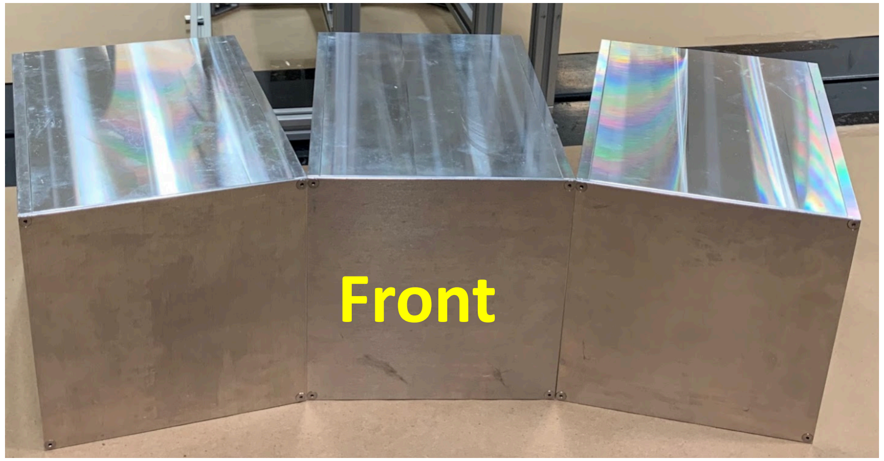


340 modules

running overlap check



284 modules

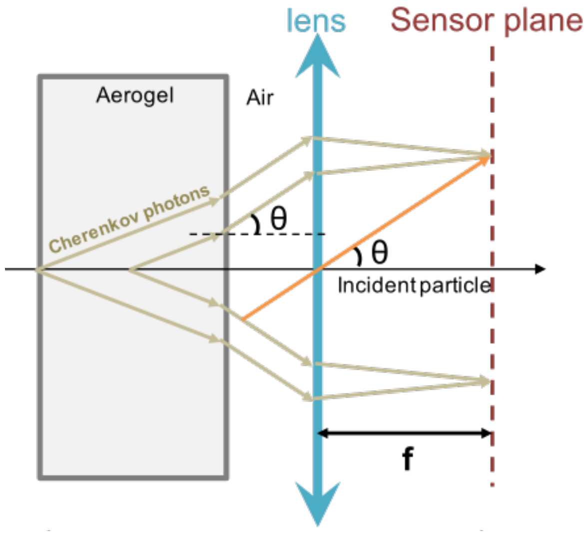


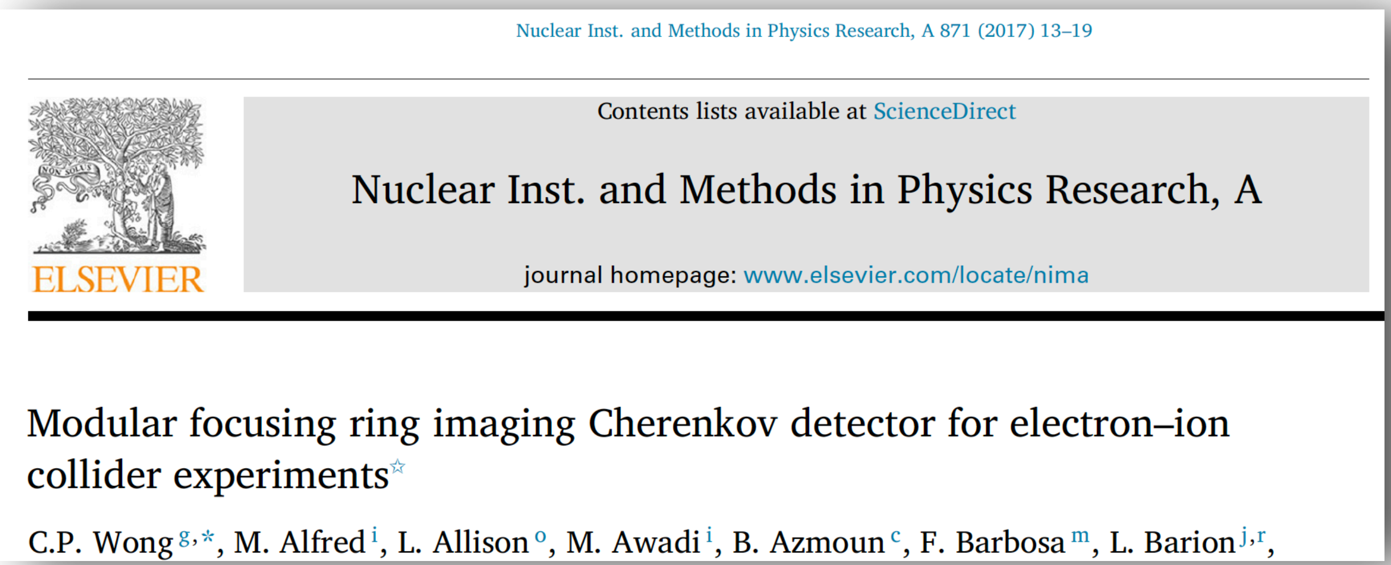
Analytical Calculation (A special case)

When particle is incident perpendicular at the center of mRICH, one can obtain the ring radius and the number of Cherenkov photons analytically. The details can be found in the appendix of the published mRICH NIM paper.

$$
\begin{aligned}
r &= f \cdot \tan\theta \\
&= f \cdot \sqrt{\frac{n^2\beta^2 - 1}{1 - (n^2 - 1)\beta^2}}.
\end{aligned}
$$

$$
\begin{aligned}
N_\gamma = {} & 2\pi\alpha L \left(1 - \frac{1}{\beta^2 n^2}\right) \\
& \times \int_{\lambda_1}^{\lambda_2} QE(\lambda) \cdot T_{aerogel}(\lambda) \cdot T_{lens}(\lambda) \cdot T_{glass\ window}(\lambda) \frac{d\lambda}{\lambda^2}.
\end{aligned}
$$





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journal homepage: www.elsevier.com/locate/nima

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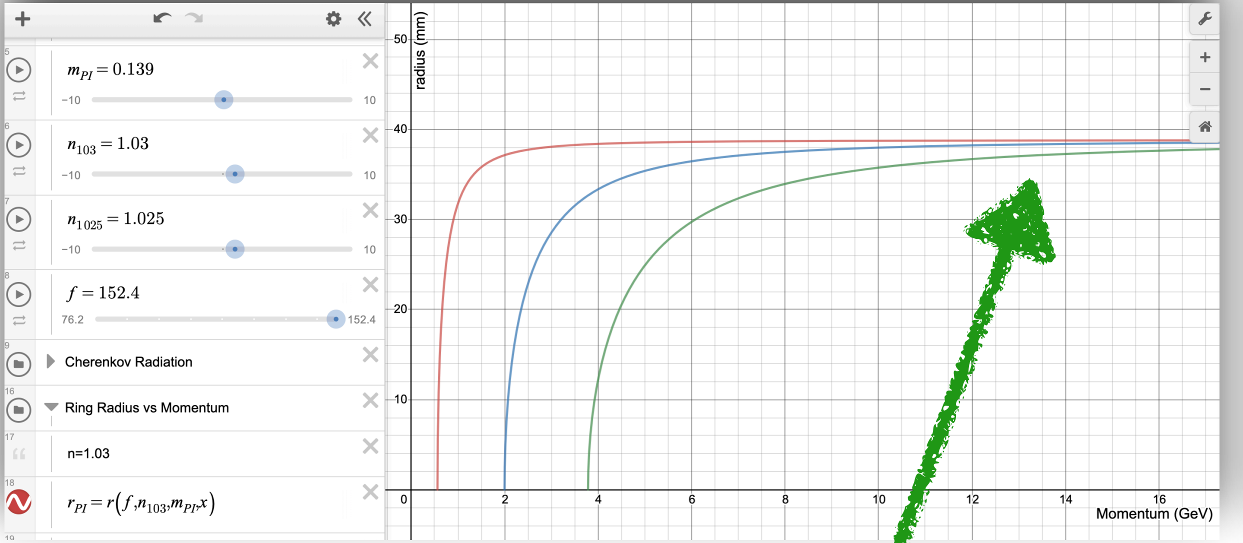
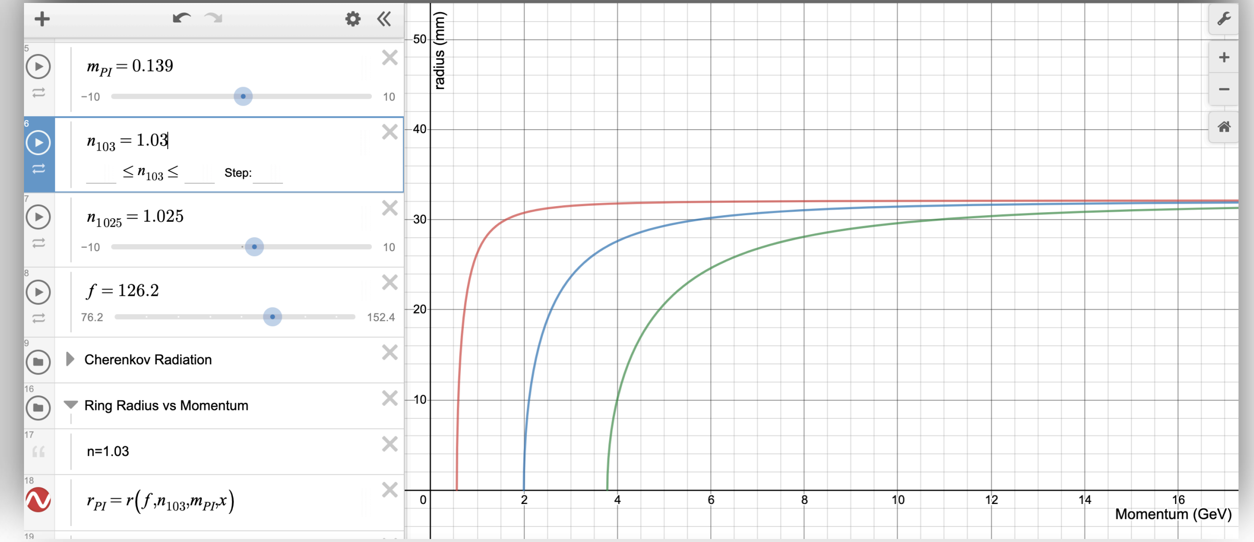
Modular focusing ring imaging Cherenkov detector for electron–ion collider experiments☆

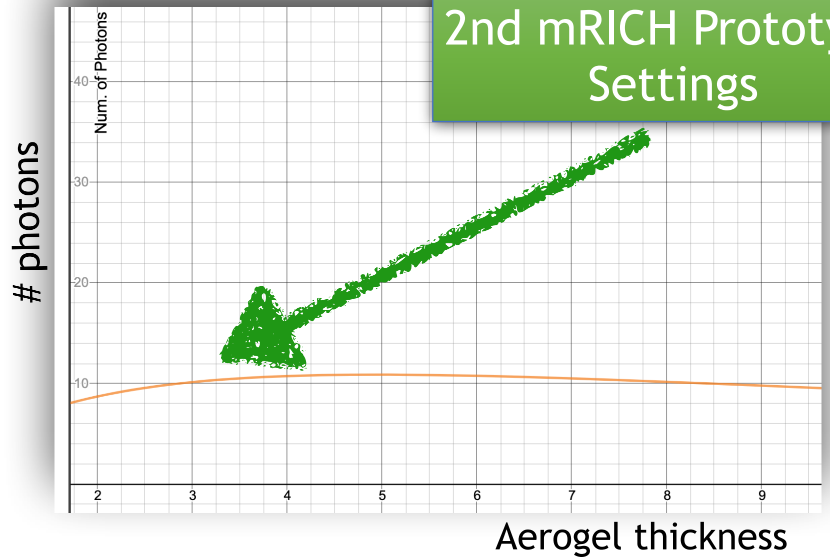
C.P. Wong[g,*], M. Alfred[i], L. Allison[o], M. Awadi[i], B. Azmoun[c], F. Barbosa[m], L. Barion[j,r],

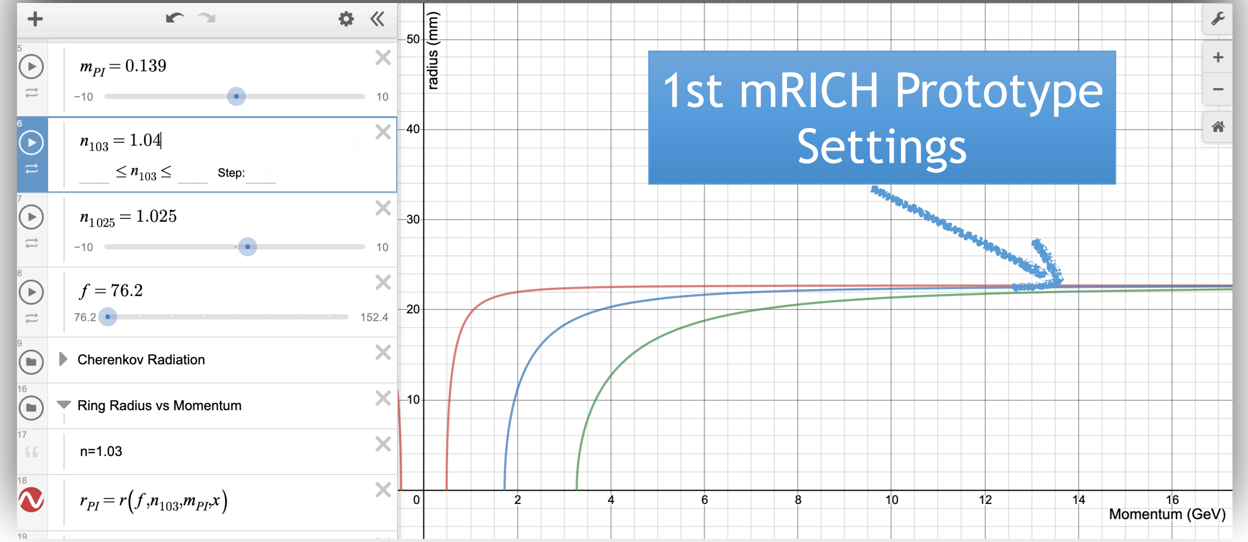
Examples from Analytical Calculations (perfect tracking!)





2nd mRICH Prototype Settings





1st mRICH Prototype Settings

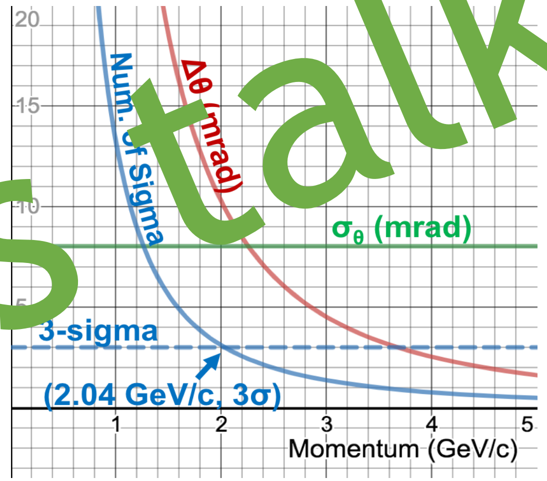
mRICH PID Parameterization

- We have implemented the pid performance (for particles entering mRICH perpendicularly as a starter) parameterization following Tom Hemmic's virtual PID base class: <mRICH.h>. This will be revised with more accurate results from GEANT4 simulations.

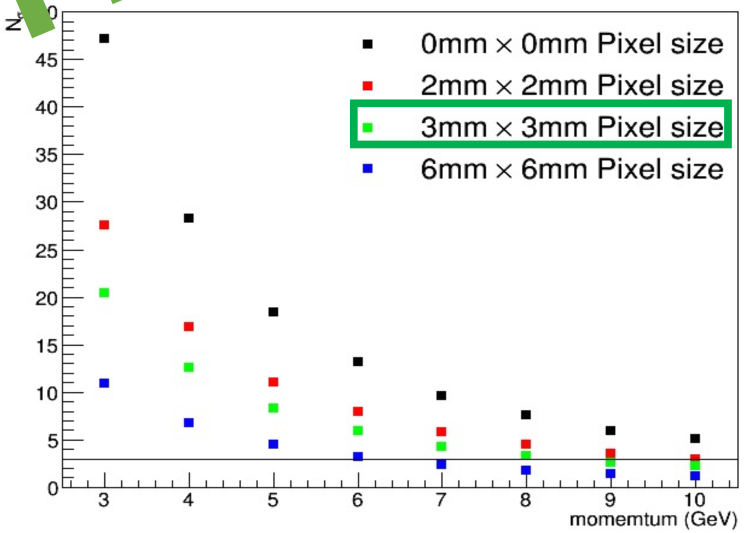
Murad's talk next

```
#ifndef __MRICH_H__
#define __MRICH_H__

// History
// Created on 3/15/2020 by Xiaochun He at Georgia State University
// for the EIC Yellow Report

// Wrapper class for mRICH (fast PID for the EIC mRICH)
//

#include "PID.h"
#include "mRICHPidFast.cxx"

class mRICH: public PID
{
public:
  mRICH(double trackResolution=0.5, double timePrecision=1.0, double pLow=3.0, double pHigh=10.0);
  virtual ~mRICH() {}

  bool   valid    (TVector3 p) {return (p.Mag() > pLow && p.Mag() < pHigh);}
  double numSigma(TVector3 p, PID::type PID);
  double maxP     (double numSigma, PID::type PID);
  double minP     (double numSigma, PID::type PID) {return 3.0;}
  string name     () {return myName;}
  void   description ();

protected:
  std::string myName;

  mRICHPidFast pid;
  mRICHPidInfo info;

  double fTrackResolution;  // resolution of the traker [mrad]
  double fTimePrecision;    // time precision of the MCP-PMT [ns]
  double pLow;
  double pHigh;
  double fSensorQMefficiency;  // photon sensor quantum efficiency
  int mRICH_ID;     //
};
```

mRICH Performance based on GEANT4 simulation



- Projected e/pi separation of mRICH 2nd prototype detector (**blue solid line**)
- 2nd prototype detector can achieve 3-sigma e/pi separation up to 2 GeV/c



- Projected K/pi separation of mRICH 2nd prototype detector (**Green dots**)
- 2nd prototype detector can achieve 3-sigma K/pi separation up to 8 GeV/c

Backup slides

Resolution, Resolution, and Resolution

From $p = \gamma m v$ one gets, $m = p/(c\beta\gamma)$ and $\left(\frac{dm}{m}\right)^2 = \left(\frac{dp}{p}\right)^2 + \left(\gamma^2\frac{d\beta}{\beta}\right)^2$.

In most cases, since γ is large, the mass resolution is determined mainly by the accuracy of the velocity measurement. The velocity measurement is given by

$$\frac{\sigma_\beta}{\beta} = \tan(\theta_C)\sigma_{\theta_C}$$

With the average angular resolution for the angle photon σ_{θ_i}, the total resolution becomes

$$\sigma_{\theta_C}^2 = \left(\frac{\sigma_{\theta_i}}{\sqrt{N_{pe}}}\right)^2 + \sigma_{\theta_{Glob}}^2$$

The term $\sigma_{\theta_{Glob}}$ combines all contributions that are independent of the single photon measurement.

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The 2nd term is similar to Tom's equation, which depends the external effects (background hits, tracking Parameters, etc). One of the goals here!

The term $\sigma_{\theta_{Glob}}$ combines all contributions that are independent of the single photon measurement.

Single photon angular resolution of mRICH

$$\sigma_{\theta_i} = \sqrt{\sigma_{EP}^2 + \sigma_{Chro}^2 + \sigma_{Det}^2}$$

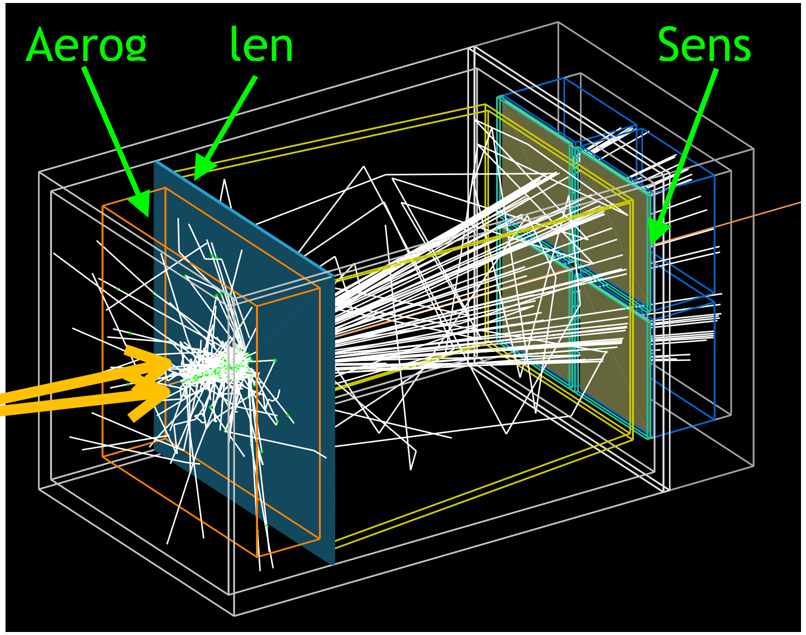
In the lens based mRICH design, σ_{EP} is minimized at the lens focal plane, σ_{Det} can be controlled with the lens focal length, and σ_{Chro} is reduced by selecting the lens transmittance in the near-UV region. As a consequence, the lens insertion improves the RICH performance at high momenta even in a compact device. Preliminary studies show that a 3σ kaon–pion separation is achievable at 10 GeV/c momentum with an aerogel of refractive index $n = 1.03$, a focal length of $6''$ and a detector pixel of 2 mm.

Tracking Requirement - Follow Tom's Example

- At any $|\vec{p}|$, there exists a "1-sigma" resolution in $\delta\theta_C$ which we'll call $\delta\theta_{C1}$
- Physics will demand that our full uncertainty follows: $\frac{\delta\theta_{C1}}{N}$.
- If we take the detector performance with a perfect tracker to be $\delta\theta_{C0}$.
- Then our external requirement on the tracker system is: |

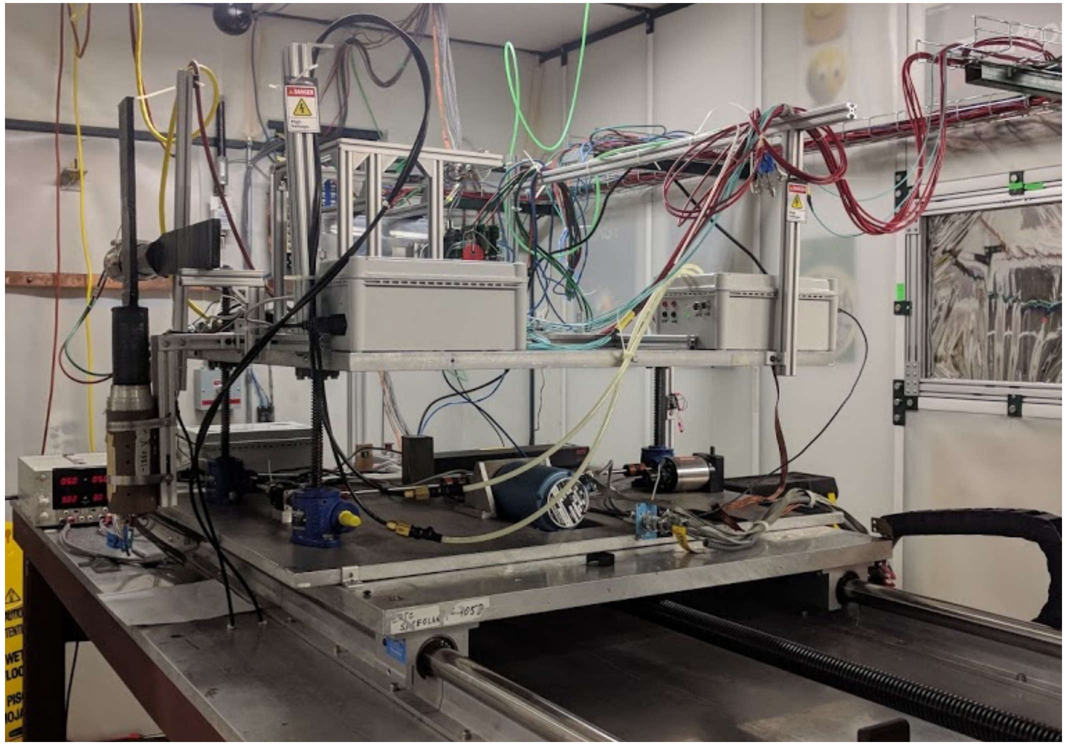
$$\left(\frac{\delta\theta_{C1}}{N}\right)^2 \le (\delta\theta_{C0})^2 + (\delta\theta_{tr})^2$$

$\delta\theta_{tr}$



mRICH 2nd Beam Test at Fermilab

120 GeV/c
proton



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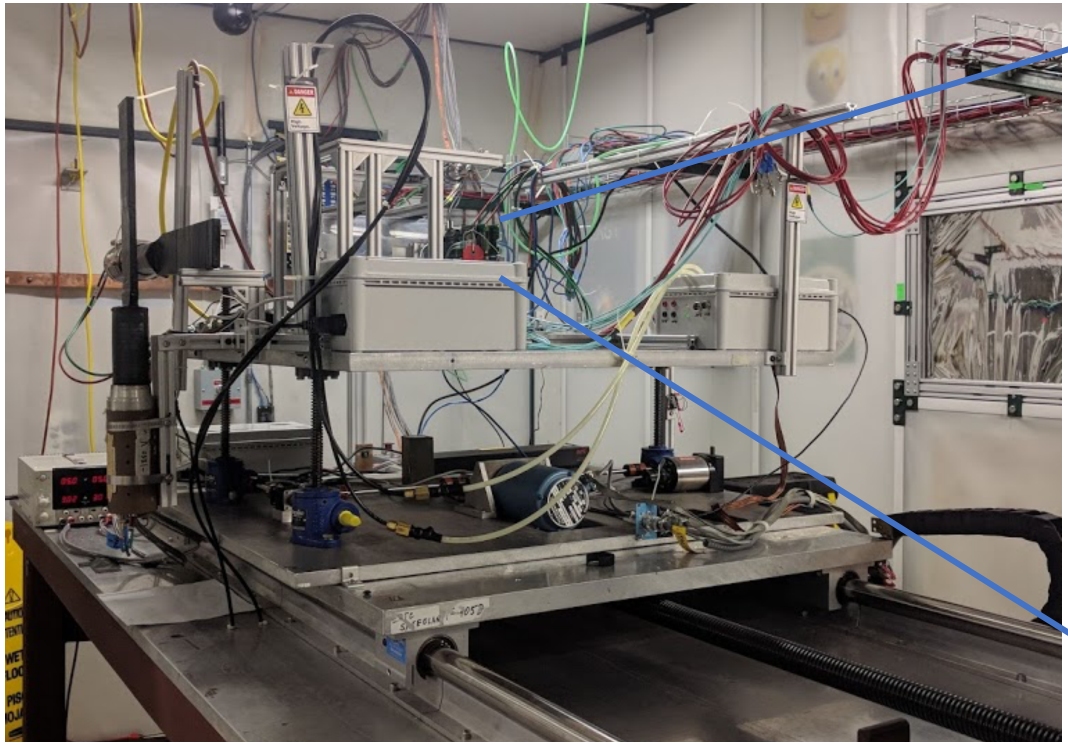
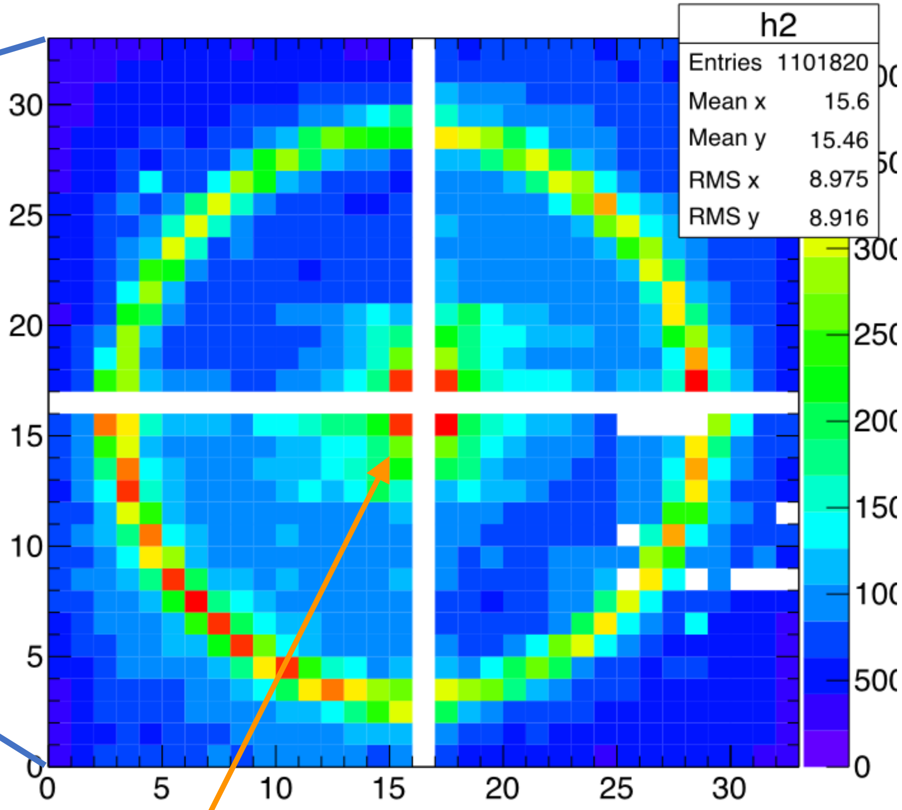


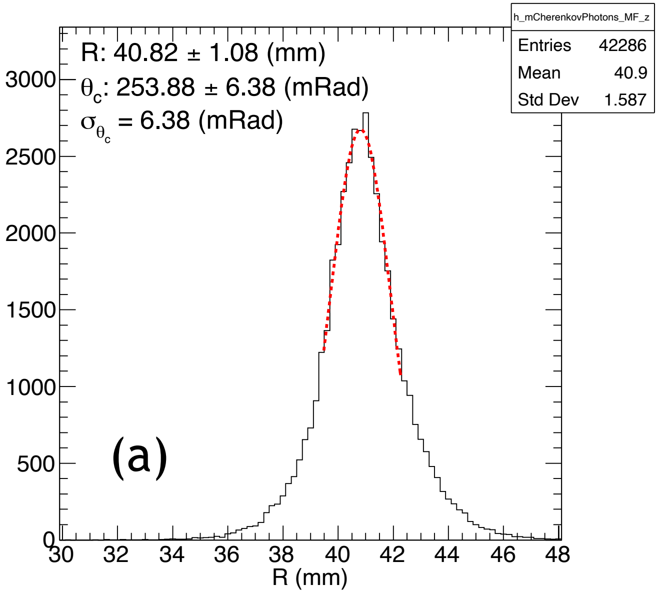


Beam spot

We already have some knowledge of poor tracking effects in the 2nd mRICH test

Data

No precision tracking was available. Beam size is ~6mm in radius.

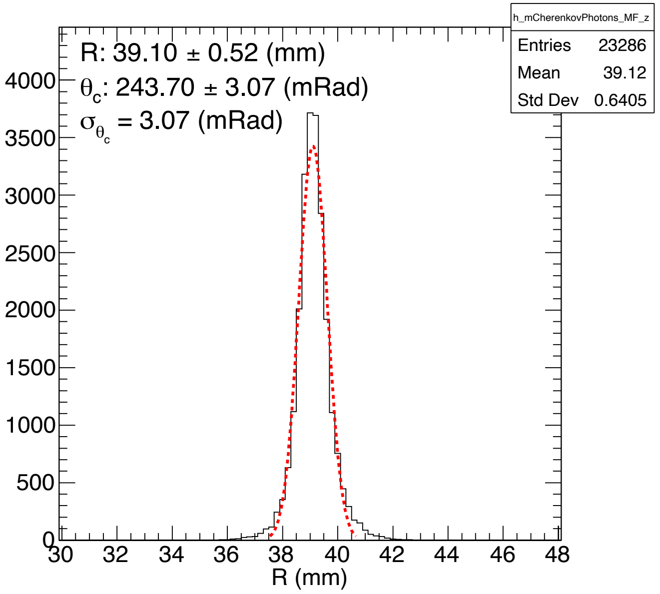


(a)

(b)

(c)

GEANT4 Simulation



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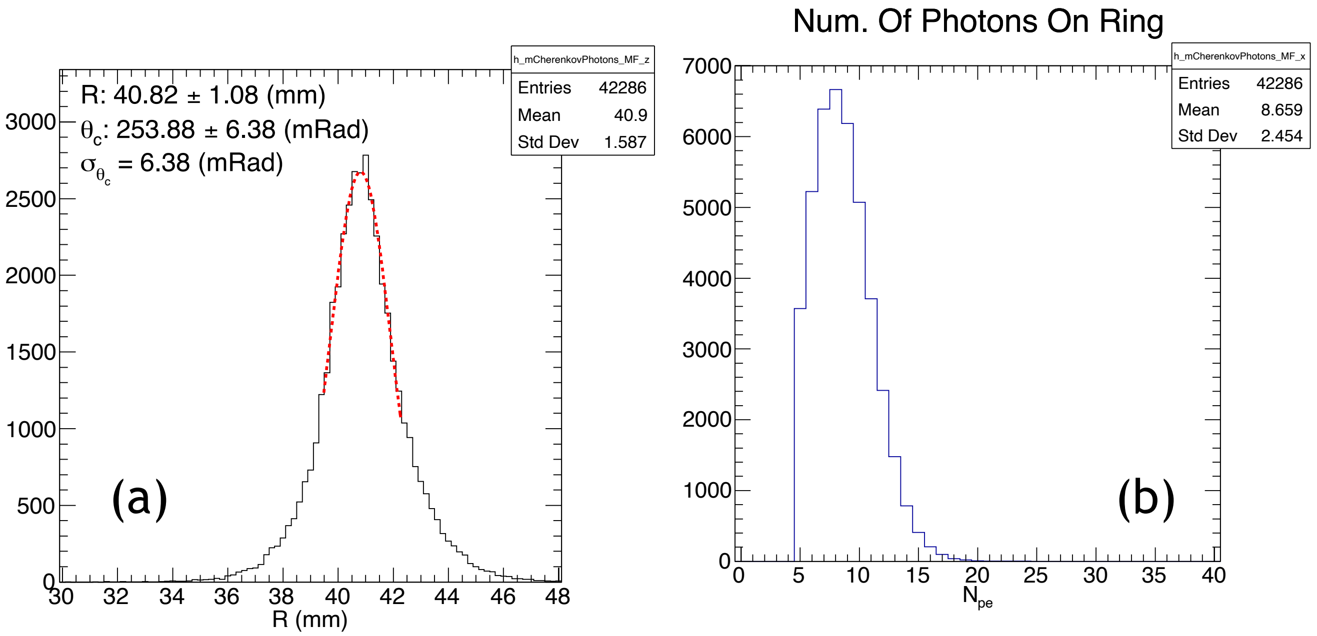
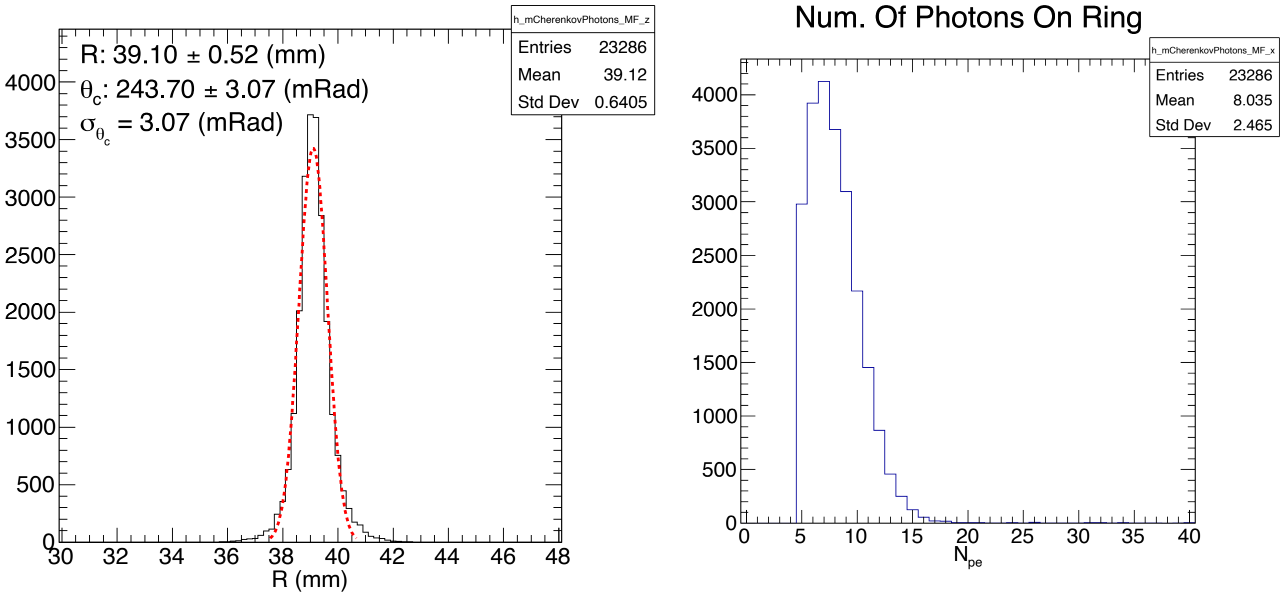


(c)

GEANT4 Simulation



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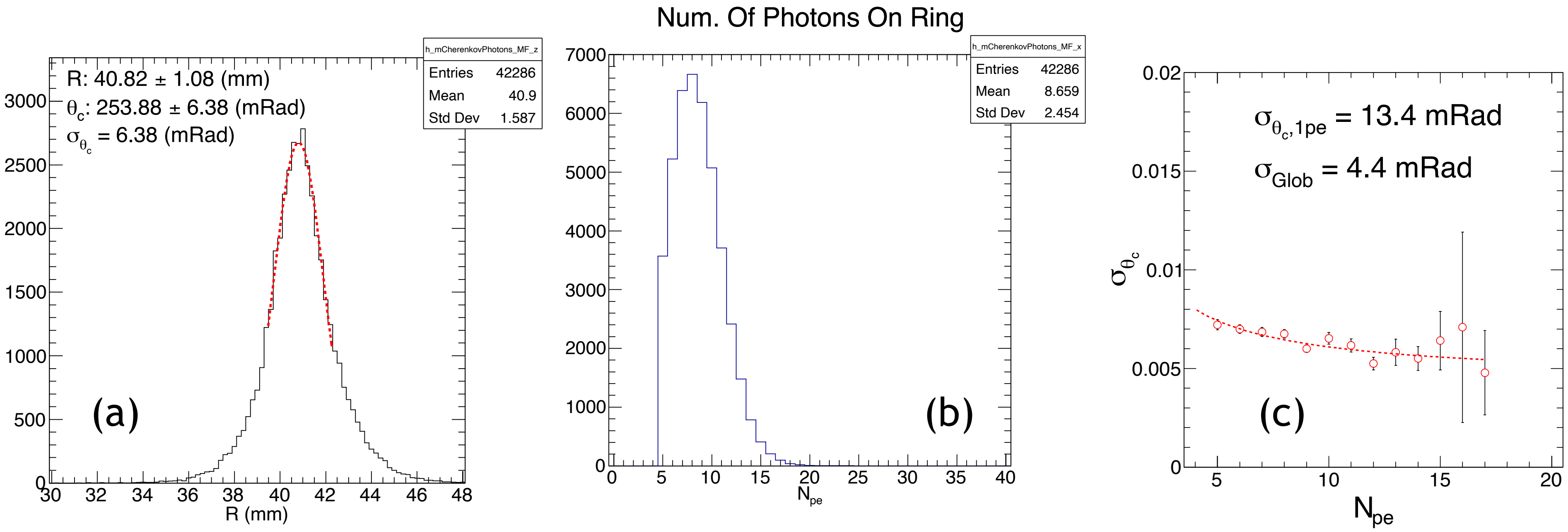

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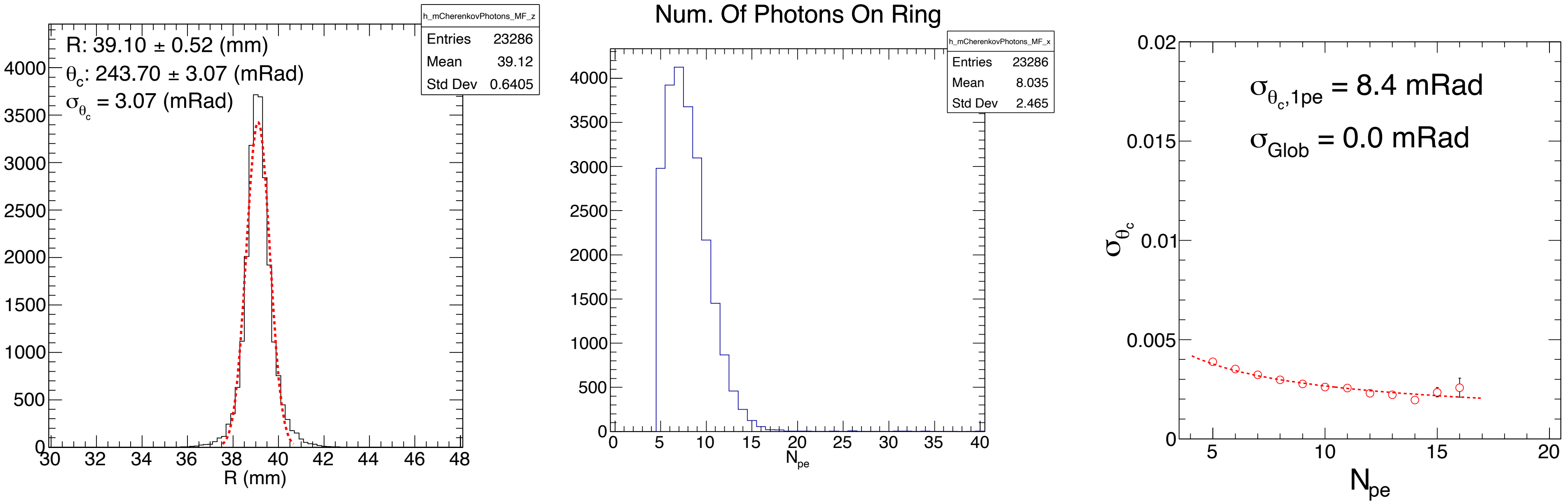

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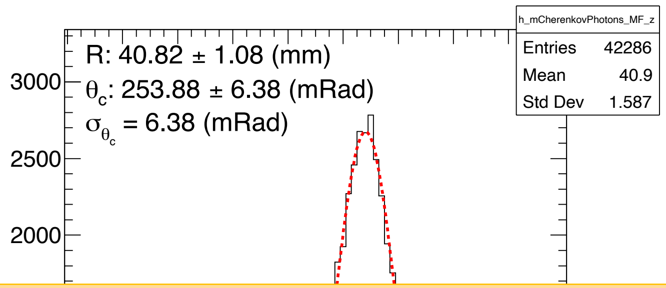

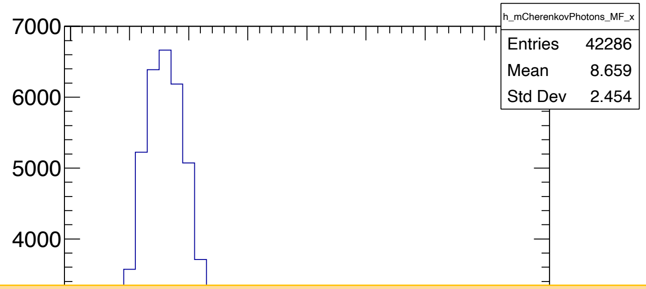

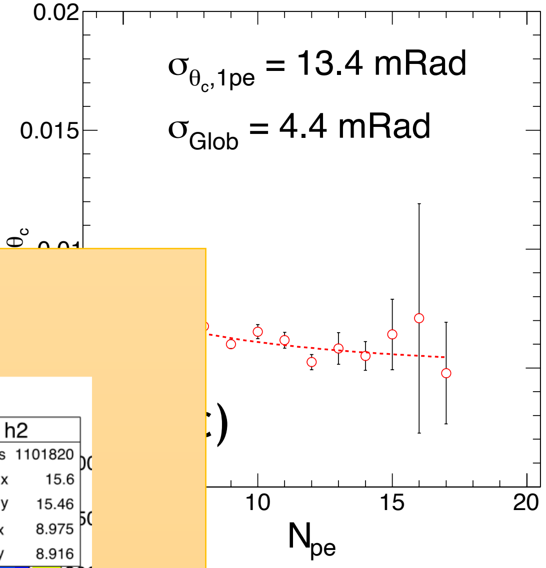

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size is ~6m
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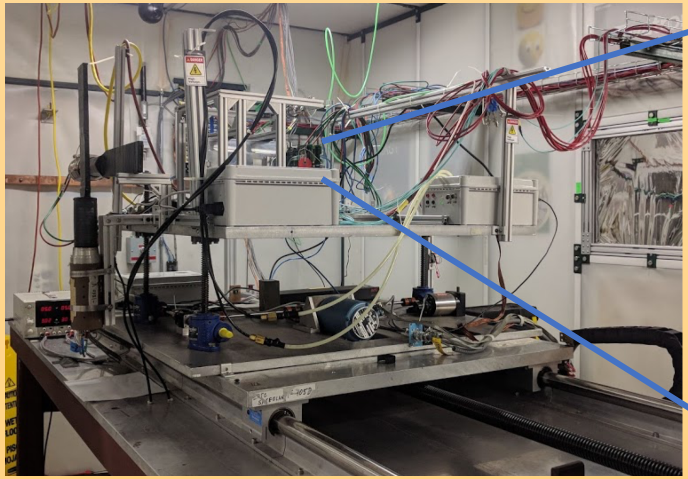
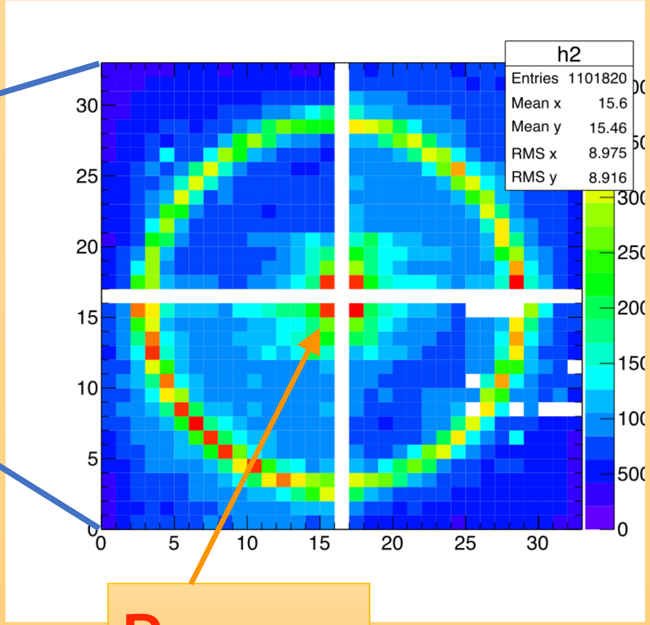
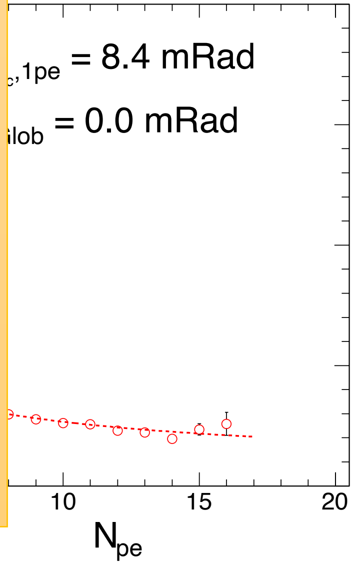
GEANT4
Simulati

120





Beam



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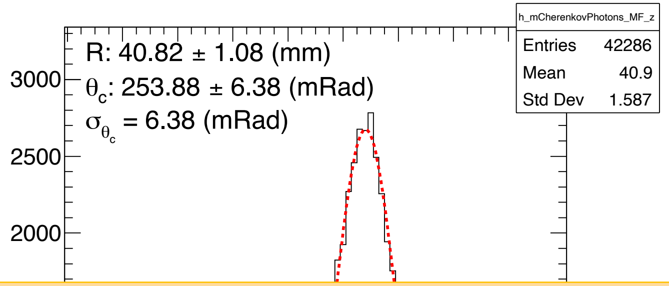

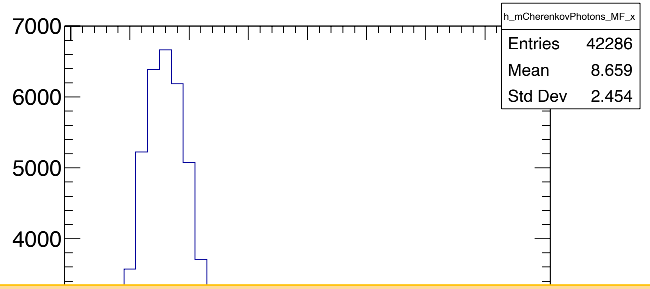

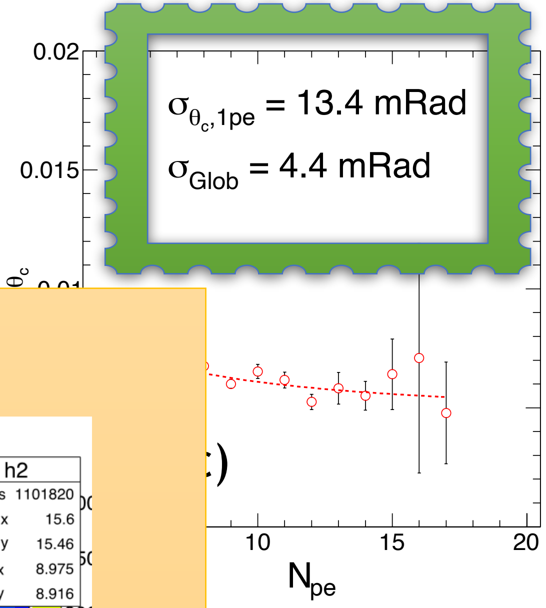

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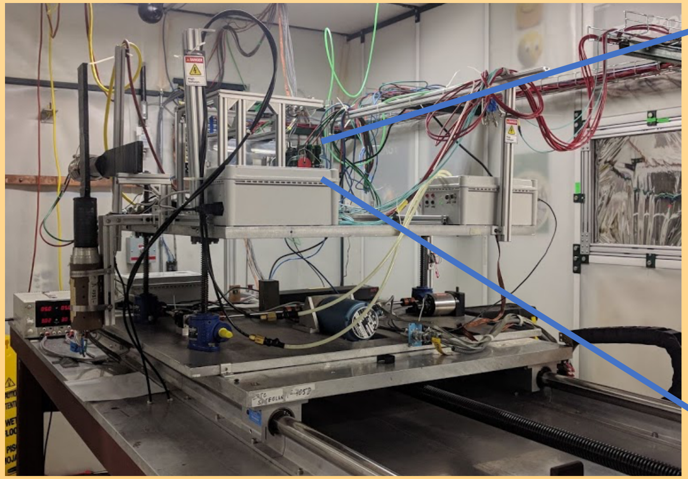
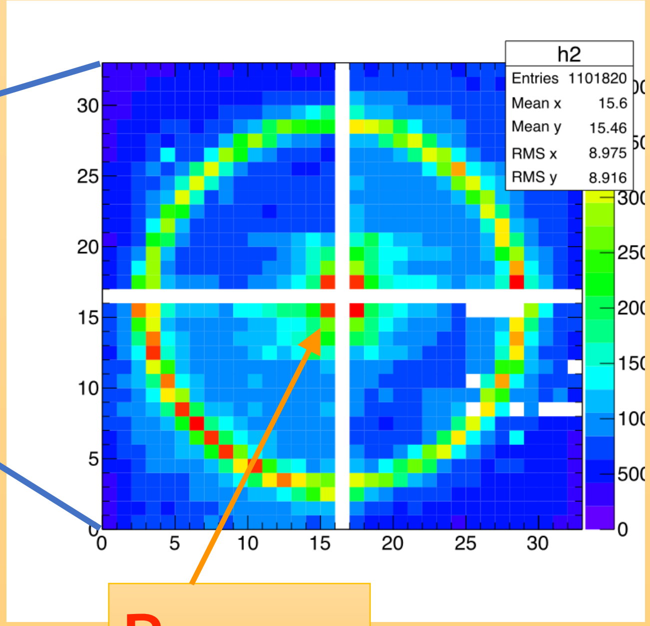
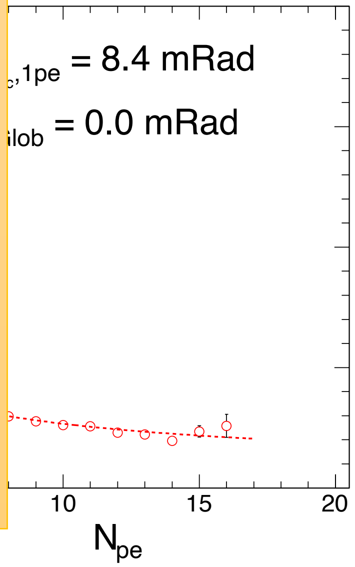
120



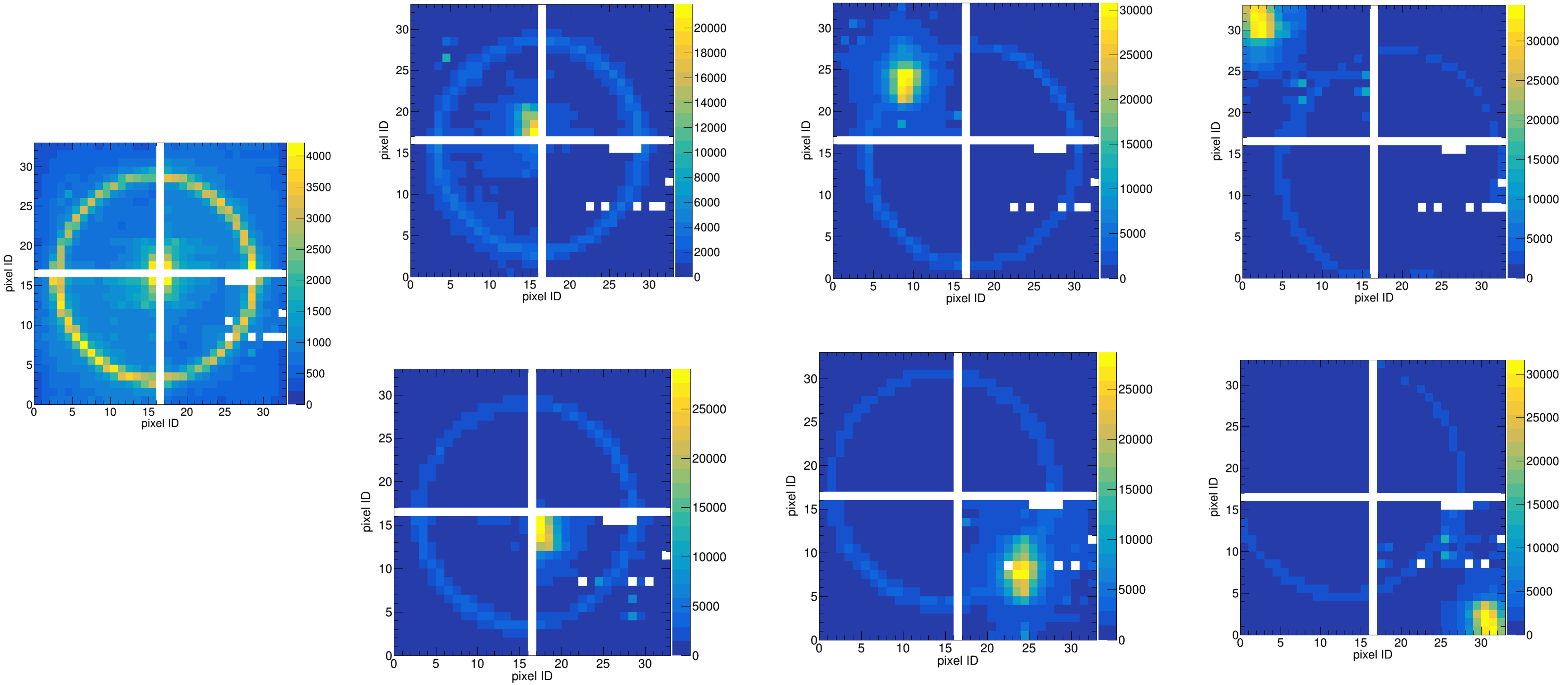


GEANT4
Simulati

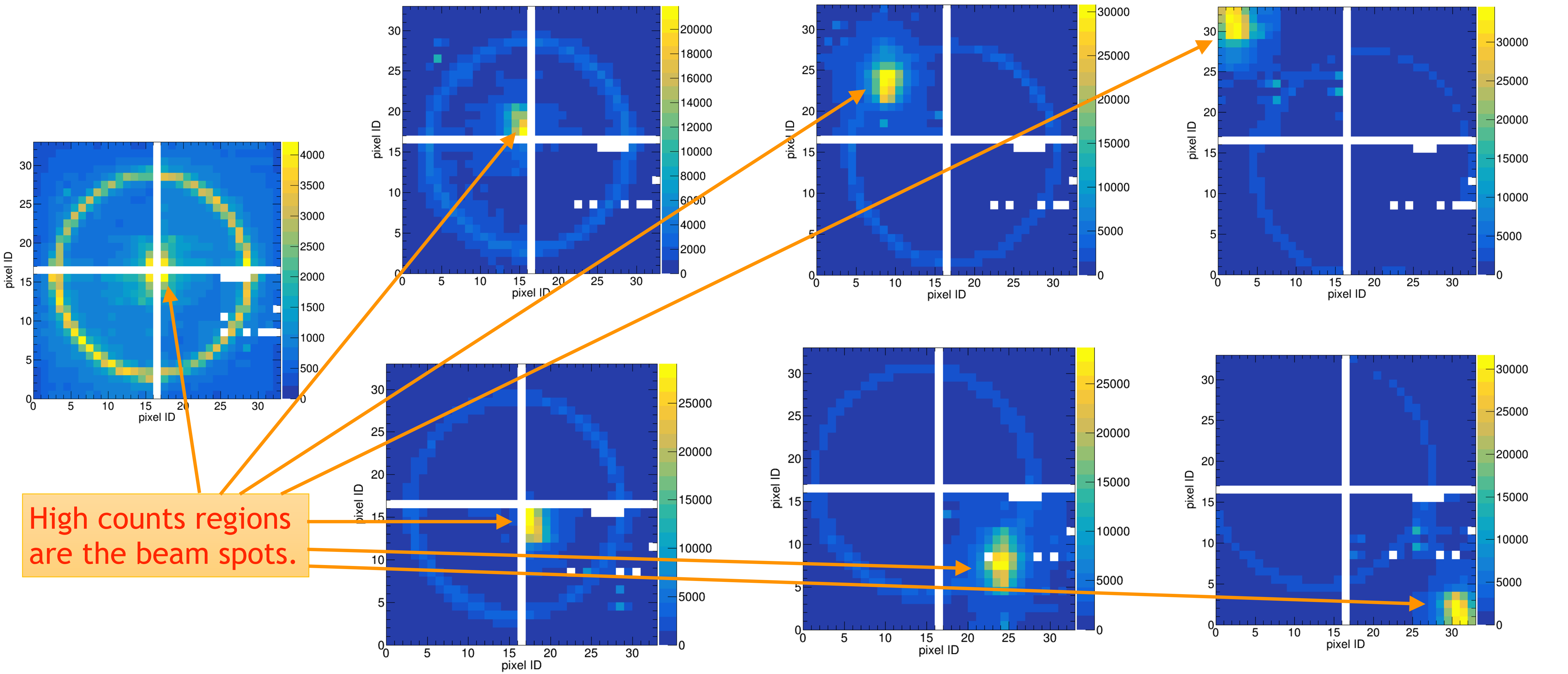


R (mm)

Position scans with 120 GeV/c proton beam

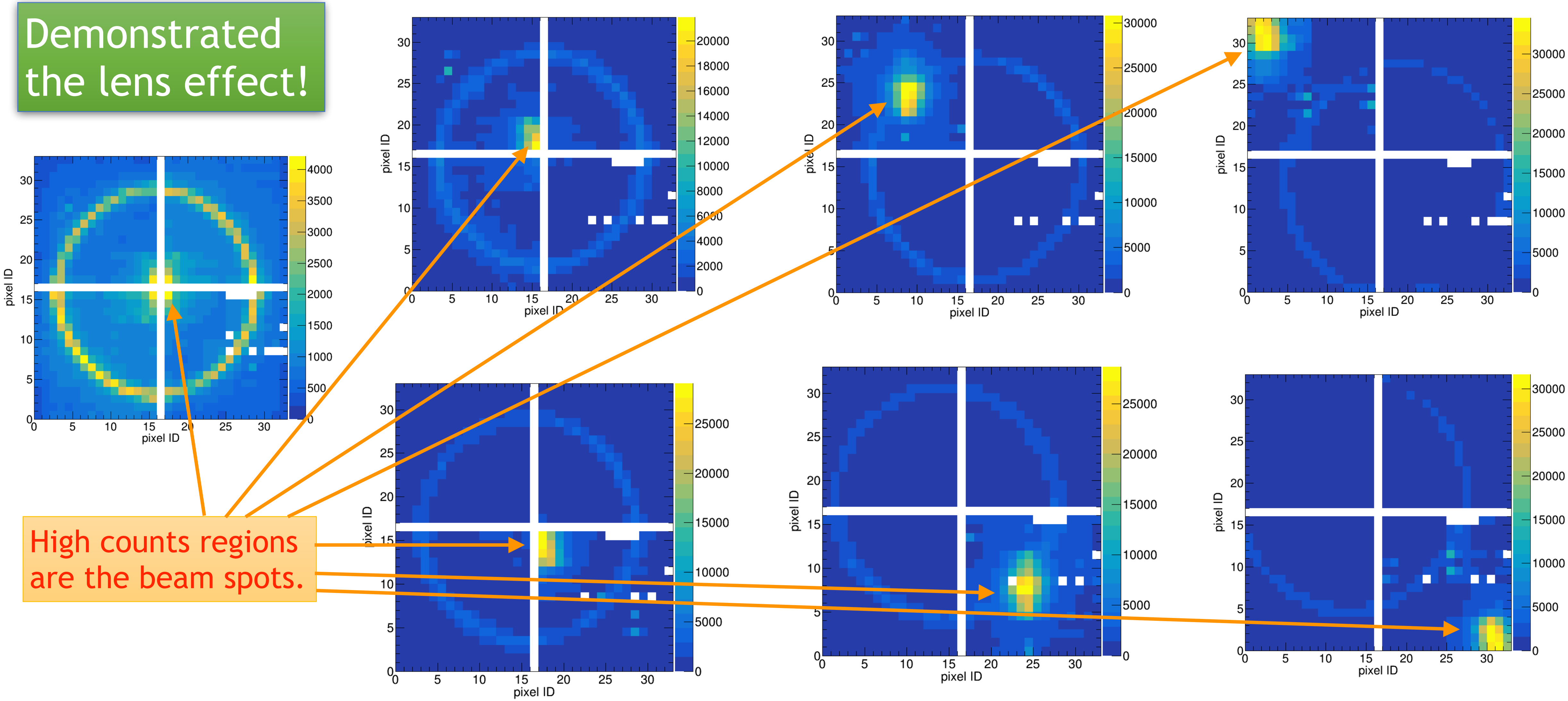


Position scans with 120 GeV/c proton beam



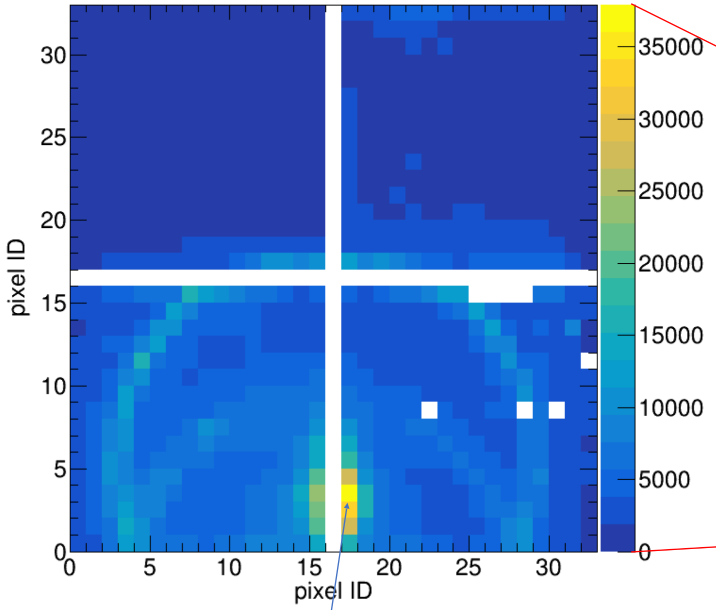
Position scans with 120 GeV/c proton beam

Demonstrated the lens effect!

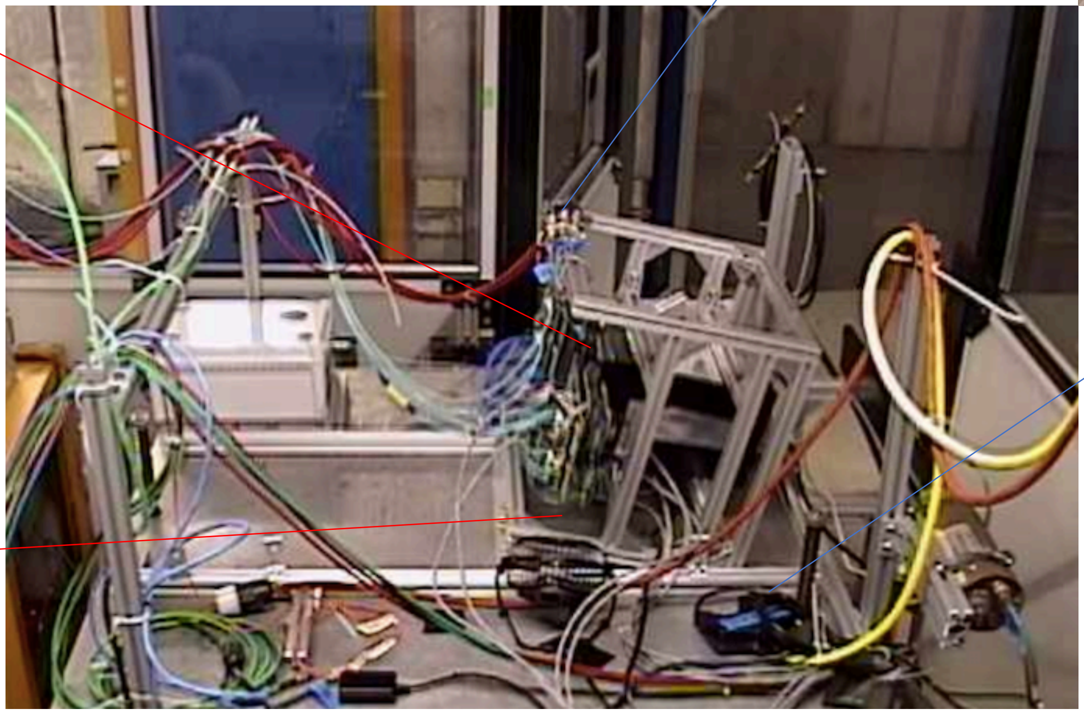


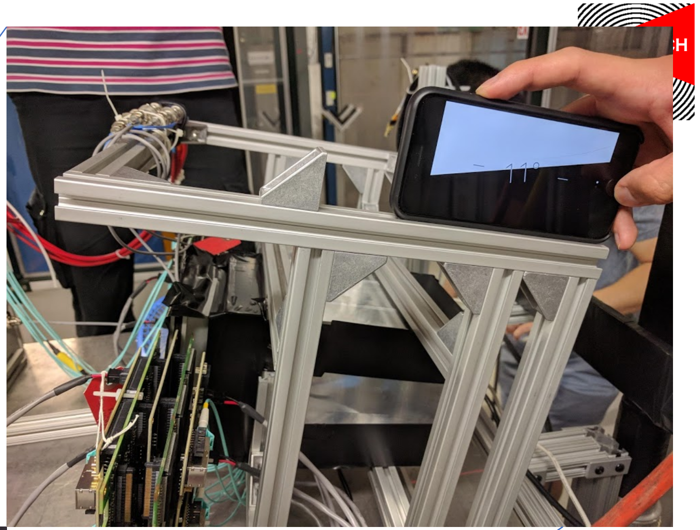
High counts regions are the beam spots.

Ring image from proton beam at an angle (11^0)



Beam spot





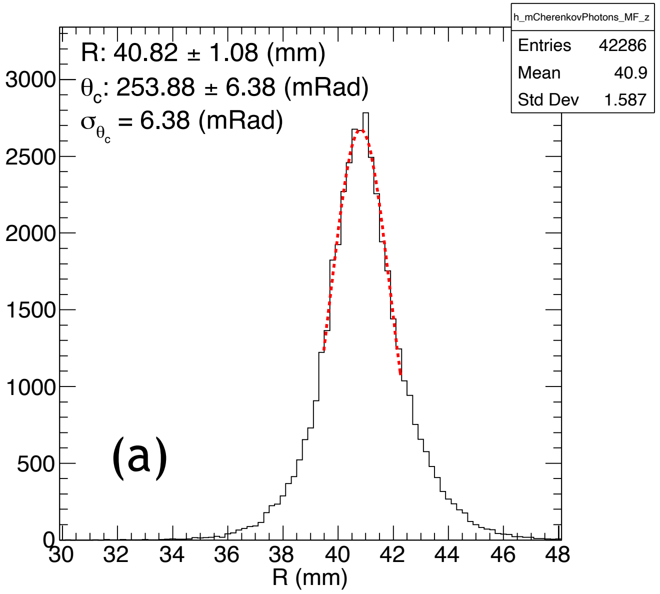
11 degree tilt downward

120 GeV/c proton beam

Ring Radius and Number of Cherenkov Photons

Data

No precision tracking was available. Beam size is ~6mm in radius.

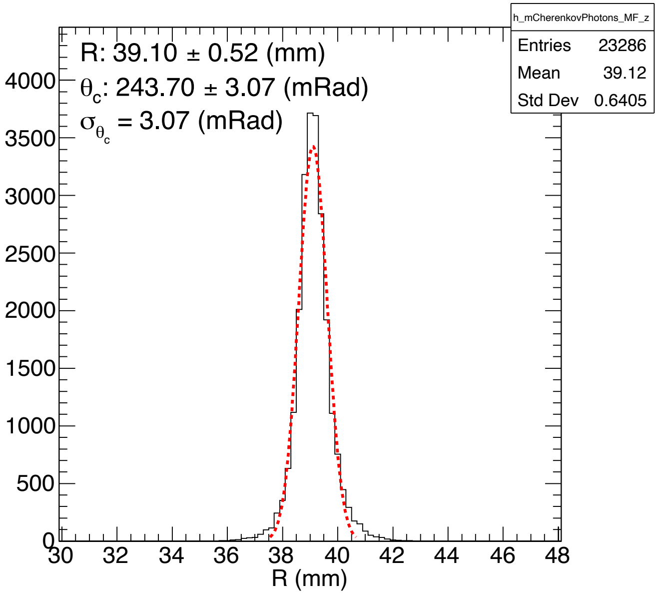


(a)

(b)

(c)

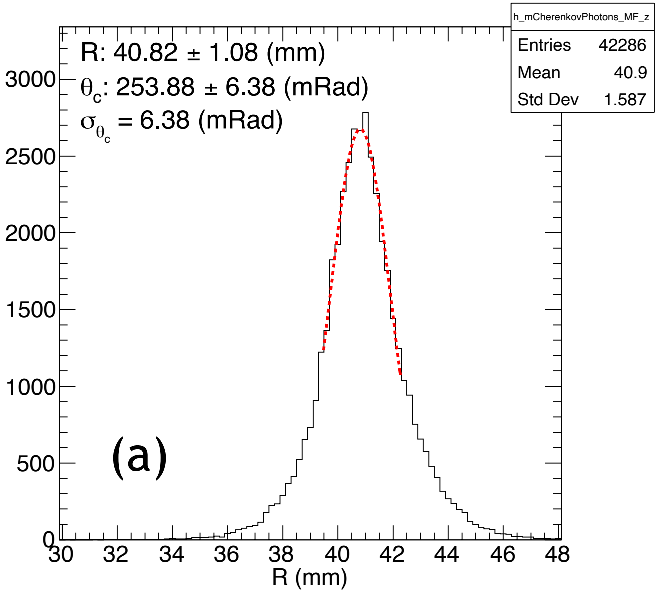
GEANT4 Simulation

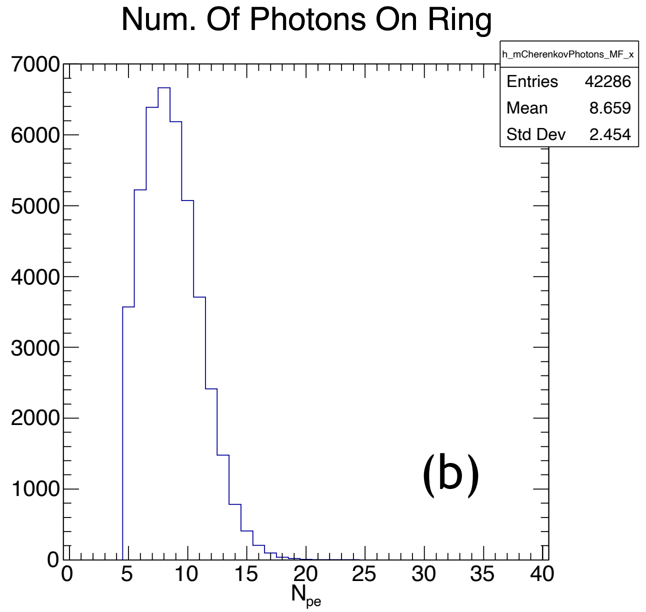


Ring Radius and Number of Cherenkov Photons

Data

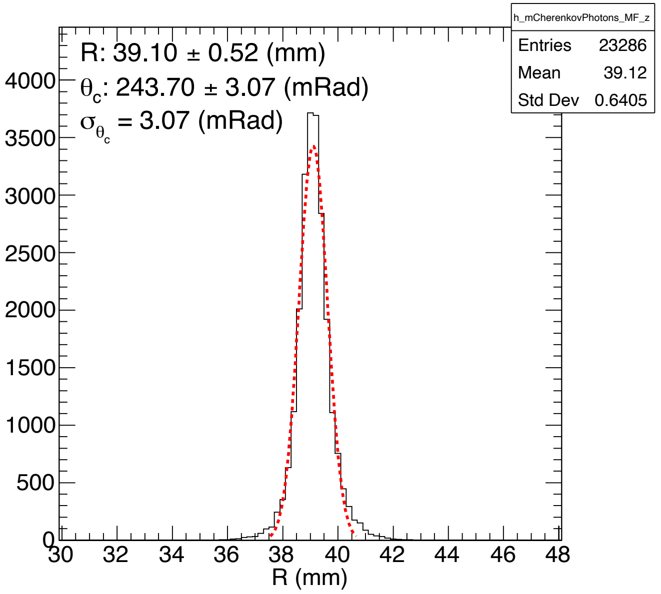
No precision tracking was available. Beam size is ~6mm in radius.

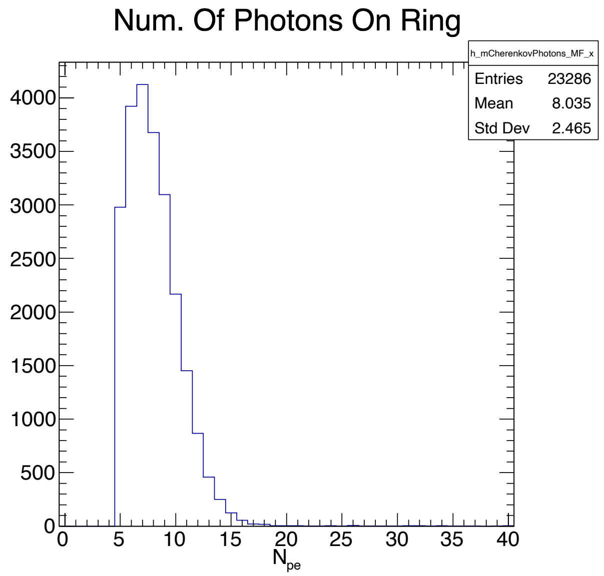




(c)

GEANT4 Simulation

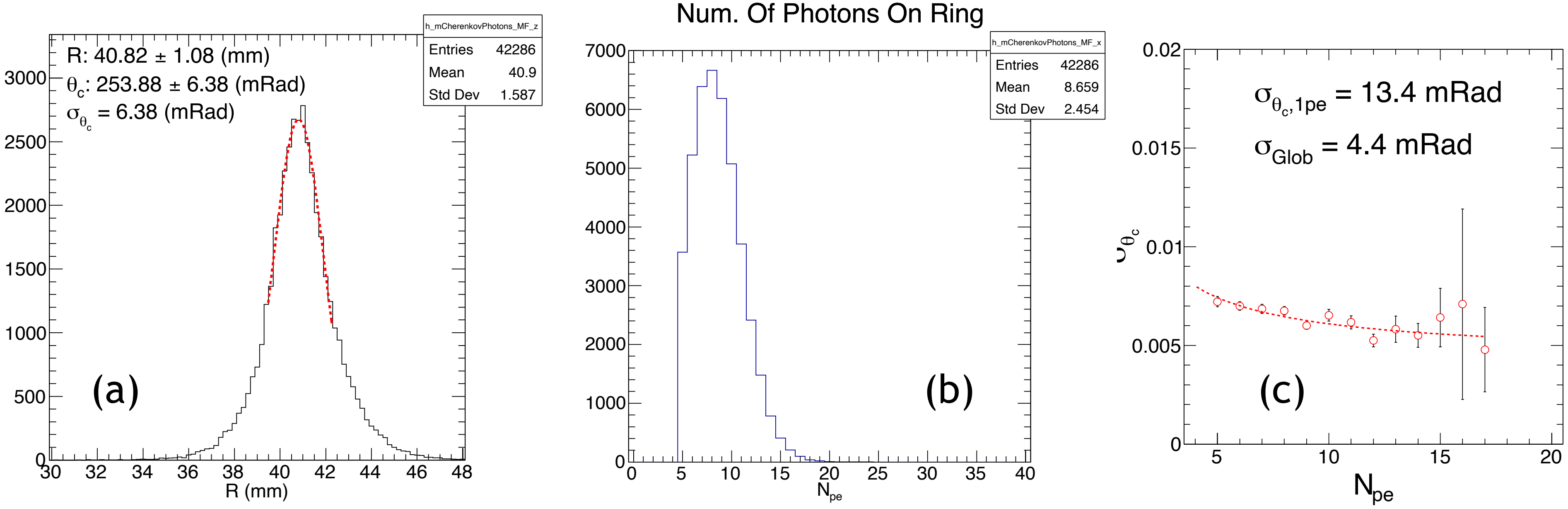




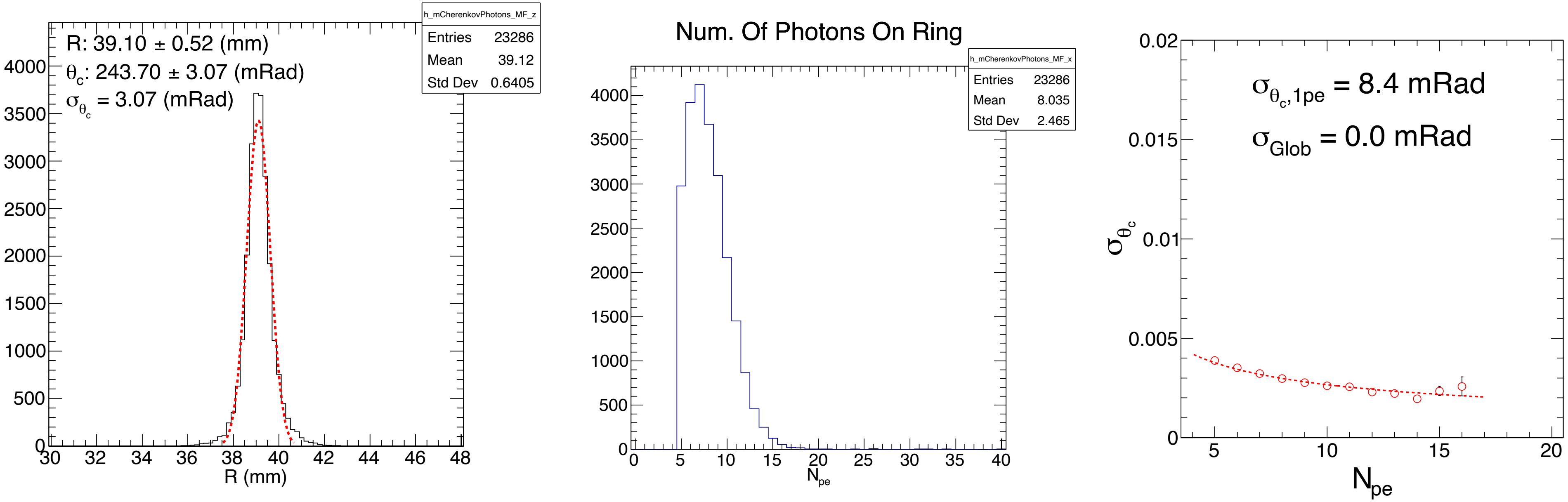
Ring Radius and Number of Cherenkov Photons

Data

No precision tracking was available. Beam size is ~6mm in radius.



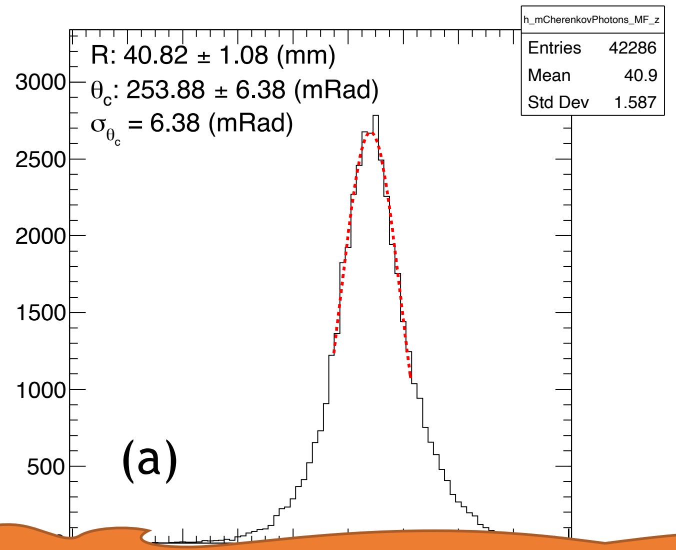
GEANT4 Simulation

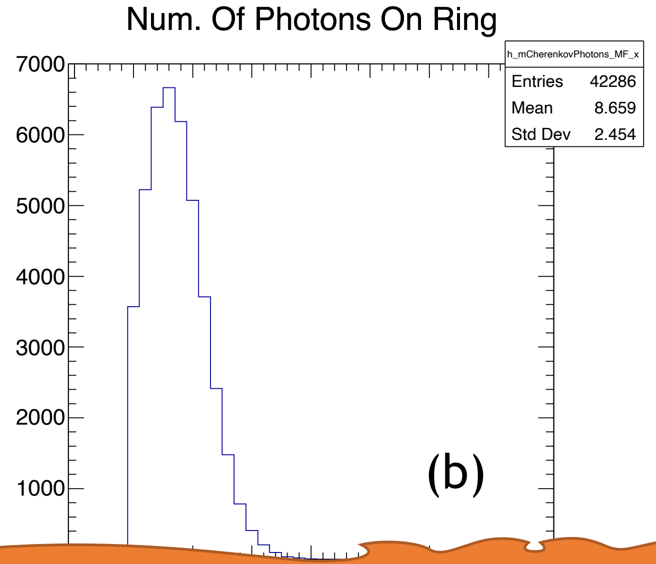


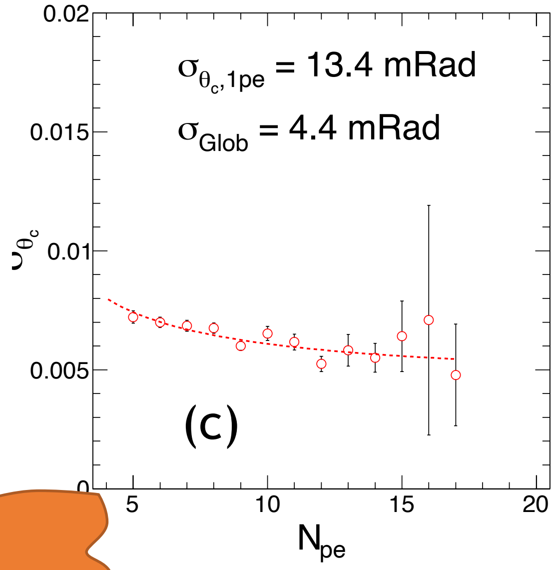
Ring Radius and Number of Cherenkov Photons

Data

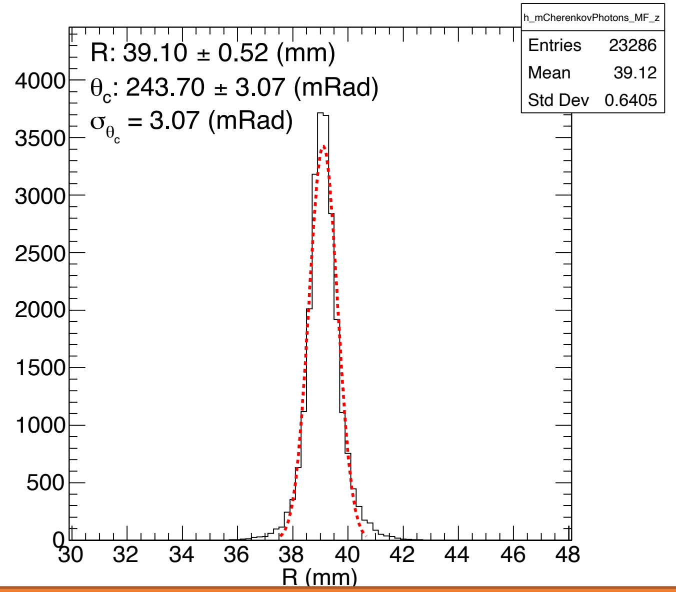
No precision tracking was available. Beam size is ~6mm in radi

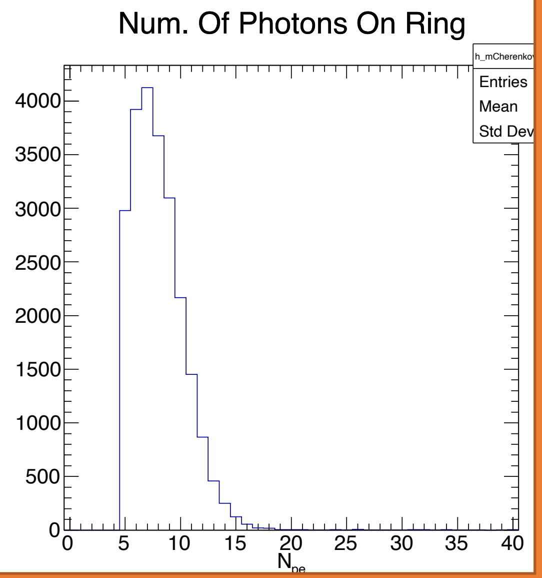


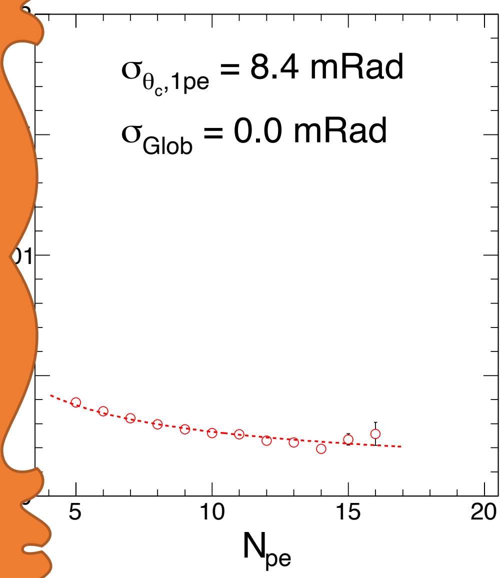




GEA
Sim







Comparison: analytically calculated values on slide 7

Aerogel + fresnel lens. NO tech risks!

3 - 10 GeV/c k/pi, <2 GeV/c e/pi

YES

YES

YES, mainly to quantify the performance

Well advanced GEANT4 simulation for the standalone mRICH

Following points will be addressed to the best of my knowledge

- Technology used: spell out clearly any risk associated, if any **Aerogel + fresnel lens. NO tech risks!**
- Momentum range covered: p versus theta and Nsigma vs. p **3 - 10 GeV/c k/pi, <2 GeV/c e/pi**
- Robustness of the design (e.g. sensitivity to magnetic field) and has a prototype been built? **YES**
- Are the electronics considerations clear (channel count, data size, rate, background) **YES**
- Time needed to complete the R&D and available workforce **YES, mainly to quantify the performance**
- Status of Simulation and Reconstruction **Well advanced GEANT4 simulation for the standalone mRICH**